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Assessment of DEMN-based IM Formulations for Octol Replacement

by Neelam Mehta, Dr. Brian D. Roos, and Dr. Eric J. Bukowski

ARL-RP-387 **August 2012**

A reprint from the *Insensitive Munitions and Energetic Materials Technology Symposium*, Las Vegas, NV, 14–17 May 2012.

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14. ABSTRACT
Octol, a high energy explosive composed of cyclotetramethylene-tetranitramine (HMX) and trinitrotoluene (TNT), is a commonly used explosive fill in several anti-armor warheads. In order to solve the viscosity problems experienced during loading, several Octol analogs were developed such as the 75/25, 70/30 and 65/35 HMX/TNT formulations. However, to meet IM requirements, shock sensitive TNT needs to be replaced within the formulations. At the October 2007 IM/EM conference, sensitivity and performance data was presented for the top three IM explosive candidates for TNT replacement. One of the three formulation candidates presented, IMX-103, is based on a nitrate salt eutectic known as the DEMN explosive. The DEMN formulation not only exceeds the TNT performance requirement, but also passed 4 of 6 IM tests including the shaped charge jet impact (SCJI) test. A sensitized formulation was later developed and demonstrated IM gains over Comp B in the 120 mm mortar projectile. Based on these previous successes, an effort was initiated to develop DEMN formulations sensitized with HMX for the replacement of TNT in the octol analogs. Small scale safety data, thermal analysis, performance and shock sensitivity are reported for various analogs of DEMN sensitized with HMX. This data will be compared to the various analogs of octols and previously characterized DEMN formulations for TNT and Comp B applications.

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ABSTRACT

Octol, a high energy explosive composed of cyclotetramethylene-tetranitramine (HMX) and trinitrotoluene (TNT), is a commonly used explosive fill in several anti-armor warheads. In order to solve the viscosity problems experienced during loading, several Octol analogs were developed such as the 75/25, 70/30 and 65/35 HMX/TNT formulations. However, to meet IM requirements, shock sensitive TNT needs to be replaced within the formulations. At the October 2007 IM/EM conference, sensitivity and performance data was presented for the top three IM explosive candidates for TNT replacement. One of the three formulation candidates presented, IMX-103, is based on a nitrate salt eutectic known as the DEMN explosive. The DEMN formulation not only exceeds the TNT performance requirement, but also passed 4 of 6 IM tests including the shaped charge jet impact (SCJI) test. A sensitized formulation was later developed and demonstrated IM gains over Comp B in the 120 mm mortar projectile. Based on these previous successes, an effort was initiated to develop DEMN formulations sensitized with HMX for the replacement of TNT in the Octol analogs. Small scale safety data, thermal analysis, performance and shock sensitivity are reported for various analogs of DEMN sensitized with HMX. This data will be compared to the various analogs of Octols and previously characterized DEMN formulations for TNT and Comp B applications.

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INTRODUCTION

The Energetic Technology Branch of the U.S. Army Research Laboratory (ARL) undertook the challenge of developing high-energy formulations with less sensitive ingredients that meet Octol performance. Incorporation of less sensitive ingredients would target formulations with larger critical diameters and reduced sensitivity to impact, shock, and thermal threats. This challenge was addressed by replacing the TNT in Octol. Supported by Project Manager–Combat Ammunition Systems, the ARL has investigated the development of nitrate salt-based eutectic mixtures, known as DEMN, to replace TNT in various weapon systems. IM tests showed a significant improvement over TNT in the M795 projectile, demonstrating improvement in 4 out of 6 tests (Table 1). The DEMN formulation passed fragment impact (FI), slow cookoff (SCO), fast cookoff (FCO), and sympathetic detonation (SD).[1] A sensitized DEMN formulation was developed as a replacement for Comp B. The DEMN explosive was optimized for performance, sensitivity, and initiability as a Comp B replacement in the 120 mm mortar. The IM tests on DEMN-filled mortars demonstrated significant improvements over Comp B in the 120 mm mortar (Table 2).[2]

Table 1: IM Scorecard for DEMN compared to TNT in the M795 artillery projectile

Explosive Fill	BI	FI	SCO	FCO	SD	SCJI
TNT	IV	IV	III	III	I	(I)
IMX-103	IV	V	V	V	III	I

Table 2: IM Results for M934 120 mm Mortars

Explosive Fill	BI	FI	SCO	FCO	SCJI	SD
DEMN-IX H	**(IV)**	**(V)**	**(III)**	**TBD**	**(III)**	**(III)**
Comp B	**I**	**I**	**I**	**II**	**I**	**I**

ARL investigated the replacement of the TNT in Octol with the DEMN melt-cast explosive. Under this study, three formulations of DEMN, HMX, and other insensitive explosive solids were evaluated. These results were utilized to assess the suitability of DEMN-based explosives combined with HMX and other insensitive ingredients to meet the performance requirements to replace current Octol formulations (i.e., 2106-A, 2107-A, 2107-B). The results also allowed for the comparison of the shock sensitivities of DEMN-based formulations prepared with HMX.

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PERFORMANCE ESTIMATES

The Octol replacement candidates were evaluated both numerically and experimentally for performance in this study. The performance was first assessed numerically using the thermochemical equilibrium code Cheetah, v5.0, developed by Lawrence Livermore National Laboratory (LLNL).[3] Table 3 presents the results of the performance calculations for each explosive at 100% theoretical maximum density (TMD). The detonation pressure (P_{CJ}), and detonation velocity (D_V) are presented as a fraction of the performance of Fine Grain Octol (FGO). The Cheetah estimates suggest that the proposed formulations will have lower detonation pressure than Octol level performance. This was expected as nitrate salt based explosives generally predict lower than their actual experimentally measured values. The detonation velocity for 2107-A and 2107-B formulation are expected to be comparable to FGO.

Table 3: Estimated detonation pressure and velocity estimates presented a fraction of FGO performance.

Performance Metric	Baseline Formulations			
	Fine Grain Octol (FGO) (65/35) HMX/TNT	**2106-B**	**2107-A**	**2107-B**
Detonation Pressure (Fraction of FGO)	1.00	0.89	0.81	0.84
Detonation Velocity (Fraction of FGO)	1.00	0.84	0.98	0.98

FORMULATION AND CHARACTERIZATION

TNT and DEMN are both melt-cast explosives. Because of their exposure to elevated temperatures during processing, it is important to evaluate these formulations on the small scale to ascertain their safe handling at elevated temperatures. After ingredient compatibility testing is completed, the melt-cast explosives are generally scaled-up from a 1-pint melt kettle to 1 and then 10 gallon scales. The need for the scale-up is determined based on the number and size of charges that need to be loaded for various types of explosive characterization testing. The test completed at the 1-pt scale on each formulation helps to determine whether they can be scaled-up to 1-gal size for measurement of detonation velocity, pressure, and shock sensitivity.

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All three sensitized formulations, developed for Octol applications, were assessed for safety and handling through small scale sensitivity and thermal stability tests. Sensitivity tests included the ERL Impact test[4], the Julius Peters BAM Friction test[5], and the electrostatic discharge test (ESD)[6]. Evaluation for thermal stability and suitability for melt casting operations were accomplished through differential scanning calorimetry (DSC)[7] and vacuum thermal stability (VTS)[8]. DSC analysis provided information such as the onset of melting and the peak decomposition temperature; VTS testing provided an indication of safe storage. In addition to VTS, it is important to determine the reaction kinetics of exothermic reactions, such as the decomposition of explosive formulations. The reaction kinetics are characterized by the Arrhenius parameters known as the activation energy and the frequency factor. The activation energies and the frequency factors were estimated for each formulation using the decomposition temperatures obtained from the thermograms at various heating rates. The critical temperature (T_C) was determined for several formulations using the Henkin time-to-explosion (TTX) test. T_C is defined as the lowest constant surface temperature at which a material of a specific size, shape, and composition can catastrophically self-heat. It is a requirement that the T_C of melt-cast formulations be determined during the small-scale safety characterization prior to scaling up to a larger kettle, such as the 1 or 10 gallon scales. All small scale testing indicated the three proposed formulations were acceptable for safe handling, storage, and use as a melt cast explosive fill (Table 4).

Table 4: Results of the small scale thermal stability and physical safety testing performed on the three replacement formulations.

Formulation Analogs	**Tests Required for Safe Scale-Up to 1 gal**			
	Ingredient Compatibility	**Impact, Friction, and ESD Sensitivity**	**Vacuum Thermal Stability**	**Processing Safety Margin**
ARLX-2106-B	Pass	Pass	Pass	Pass
ARLX-2107-A	Pass	Pass	Pass	Pass
ARLX-2107-B	Pass	Pass	Pass	Pass

PERFORMANCE AND SHOCK SENSITIVITY

All three formulations were evaluated for both performance and shock sensitivity. Shock sensitivity was assessed using the Naval Ordnance Laboratory (NOL) Large Scale Gap Test (LSGT). Table 5 presents the results of the testing as fractions of FGO performance. All three replacement formulation outperformed the three commonly fielded Octol formulations by greater than 40% of FGO. Two of the formulations, 2107-A and 2107-B, were remarkably less sensitive than FGO (>54%).

Table 5: LSGT results presented as a fraction of FGO performance.

NOL Shock Sensitivity	
Formulation	**Pressure** (Fraction of FGO)
FGO (65/35)	1.00
Octol (70/30)	> 0.70 and < 1.00
Octol (75/25)	0.70
ARLX-2106-B	1.67
2107-A	2.48
2107-B	2.17

The detonation velocity was measured using two techniques. The first was from a vertical series of equally spaced piezoelectric pins and the second was from a similarly positioned series of fiberoptic cables. Photographs for both of the experimental testing setups can be seen in Figure 1. The detonation velocities for the three formulations are presented in Table 6 as a fraction of FGO velocity. The detonation velocities for 2107-A/B were comparable to FGO while 2106-B was 2% higher. The detonation pressure was assessed computationally using the experimentally measured detonation velocities and Equation 1. The detonation pressure of 2106-B was comparable to the detonation pressure of FGO and 2107-A/B were within 10 and 12% respectively.

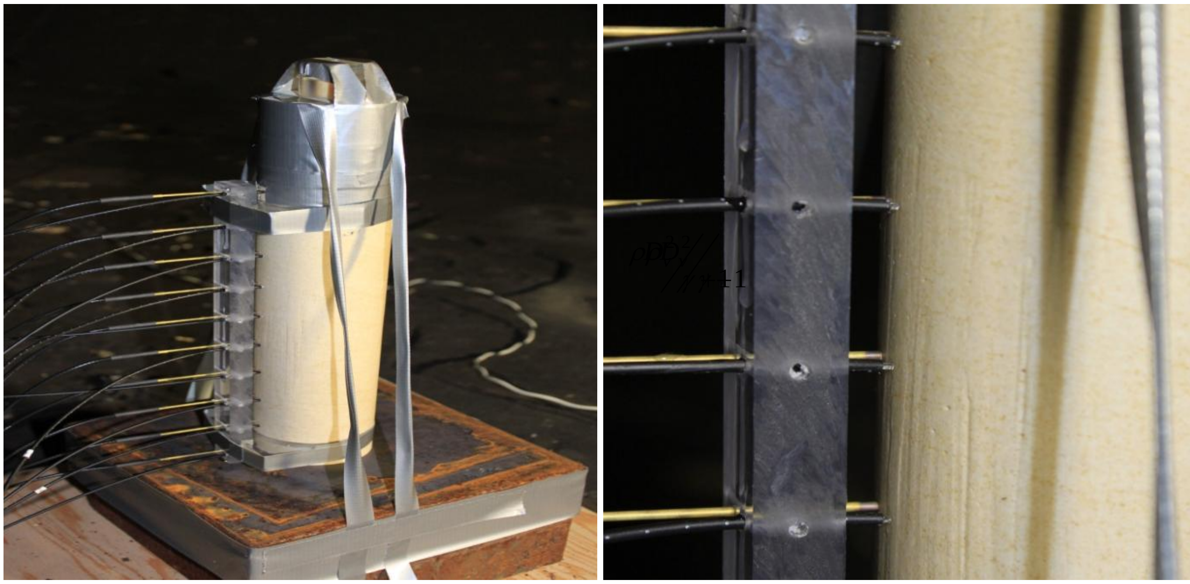

Figure 1: Images of the experimental setup for the determination of detonation velocity (left) and a close up image (right) of the fiber optic and piezoelectric pin holder design.

Table 6: Experimentally determined detonation velocities and detonation pressures presented as a fraction of FGO performance.

	> 1 inch Unconfined	
2106-B	**Detonation Velocity (Fraction of FGO)**	**P_{CJ} (Fraction of FGO)**
FGO	1.00	1.00
2106-B	1.02	0.99
2107-A	0.97	0.88
2107-B	0.98	0.90

Equation 1: Detonation Pressure

$$Pcj = {}^{\rho D_v^2}\!\big/_{\gamma + 1}$$

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SUMMARY AND CONCLUSION

This effort, tasked with the development high-energy formulations with less sensitive ingredients meeting Octol performance produced three possible replacements. Small scale safety data, thermal analysis, performance and shock sensitivity was reported for the formulations containing DEMN, various ratios of HMX, and other insensitive solid HEs. Small scale thermal and physical testing indicated the three proposed formulations were acceptable for safe handling, storage, and use as a melt cast explosive fill. The formulations were then subjected to NOL LSGT protocol as well as detonation velocity measurements. The reduced sensitivity and comparable detonation pressure and velocity values suggest that all three formulations are a suitable replacement candidate for Octol. Formulation 2107-A was the most insensitive while 2107-B provided the best compromise between shock insensitivity and comparable Octol performance.

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